PETROLOGY OF THE GRANITIC ROCKS IN DUDRAN AREA, DISTRICT BARAMULLA JAMMU AND KASHMIR

by

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This is to certify that Mr. Zurar. S. Ahmad has completed his research work, presented in this thesis, under my supervision for the degree of Master of Philosophy of the Aligarh Muslim University, Aligarh. This work is original and has not been submitted for any degree at this or any other university.

(SYED M. ZAINUDDIN)

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C O N T E N T S

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Chapter One

INTRODUCTION

The Central Himalayas, a part of which forms the area of the present study, exposes a gamut of Precambrian metamorphites, younger sedimentaries and concordantly and discordantly emplaced igneous intrusives and also the extrusives. Out of this gamut, the granites which form the Central Himalayan axis are of utmost significance, as an understanding of their tectonomagmatic cycle will go a long way in deciphering the evolutionary and tectonic history of these complex mountain ranges. In the present programme of study an attempt is being made to provide some data on the Dudran Granite, which may be helpful in eventually deciphering the tectonomagmatic cycle of the granite.

The granitic rocks of the Central Himalayan axis can broadly be distinguished into 1) Older (poly-metamorphic) granites; and 2) Younger, leucocratic, tourmaline granites of Mio-Pliocene age (Pascoe, 1950; Valdiya, 1962; Ray, 1972; Ghose and Singh, 1977; etc.).

1) The older (poly-metamorphic) granitic gneisses, augen gneiss and banded gneisses, which are associated with the high-grade metamorphites and migmatites of the Lower Himalayas, belong to the Hercynian orogeny, (Pascoe, 1950). Gansser (1964) and Ray (1972) assign these granites a Tertiary age. Spatially these granites occur within the Precambrian rocks in the Western Punjab-Ladakh-Karakoram end of the Himalayas, and are emplaced along thrust planes (Desio, et al., 1964).

2) The younger, leucocratic, tourmaline granites of Miocene to Pliocene age, forming some of the loftiest peaks of the Higher Himalayas, occur as intrusives into the younger sediments (Tanawals, Murrees, etc.), are undisturbed and have

associated lamprophyre, trachyte and pneumatolytic phases (Gansser, 1964, b). These are late to post orogenic granites and represent the last phase of completely mobilised material intruded from deeper levels into the upper horizon, during the Himalayan tectono-magmatic cycles (Gansser, 1964, b).

Ray (1972), believes that both the types of granites formed either at the present surface, or were brought to it from greater depths where they had formed and were uplifted in the solid state. He also considers the separate spatial distribution of their major occurrences as suggestive of genetic differences.

Compositionally the Himalayan Granites range from granite to quartz diorite. Divergent views have been put forward to explain the origin of the Himalayan granites; e.g. the Bandal Batholith of Himachal Pradesh has been considered as metasomatic by Parthasarthy (1969) and magmatic by Sharma (1977).

Most studies on the Himalayan granites have been confined to certain key areas; e.g. in parts of central and eastern Himalayas. The western bodies have not been studied in detail; these include the batholithic masses of the Nanga Parbat, Kozi Nag, the Jagran boss and the Hant massif, the granites of Dudran, Gulmarg, Banihal, Ramban, etc. All these bodies intrude the Salkhala metasediments and are believed to have the same regional strike, (pers. comm. Ansari, 1977). This probably means that the various granitic bodies in the region are, in fact, part of one massive batholitic mass, covering thousands of sq.kms., right across the Himalayas, and are not separate bodies as earlier believed, but different phases of the same intrusion.

The Dudran granite, which forms the subject of the present study, lies in the Rampur-Apharwat section of the Salkhalas in the Pir Panjal Range and is emplaced in the Gulmarg Anticlinorium (Wadia, 1934). To date, this granite has not been studied in detail and its petrology, mode of origin and emplacement are not clearly known. The programme envisages deciphering the various intrusive phases of the Dudran granite and their relationship with the tectonic history of the area.

<u>Geography and location</u> :-

The area lies approximately 90 kms. to the NNW of Srinagar, in Baramulla district, on the Uri-

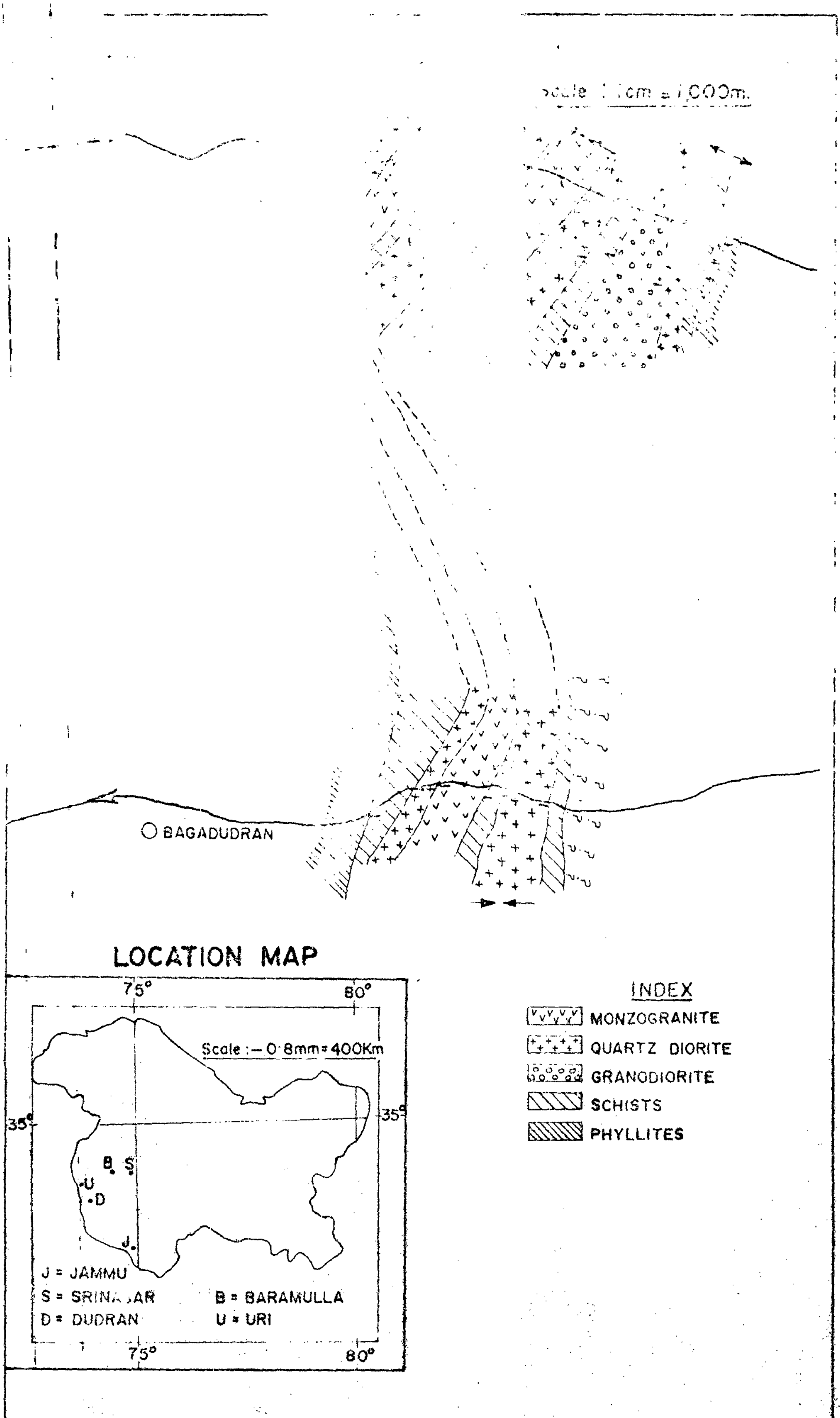

Fig. 1: GEOLOGICAL MAP OF THE DUDRAN AREA

Srinagar Highway (Fig. No. 1). The area is approachable from Srinagar upto Buniyar, 80 km. on the Uri-Srinagar Highway, whence a fair-weather road leads to Baron, 10 kms. from Buniyar. From Baron, the Dudran Hamlet is 4 kms. to the east and is reached by a foot-track.

The area forms part of the Jhelum Drainage system. The Dudran and Baga Dudran Nalas are the major drainage arteries, flowing in a roughly E-W direction, and their morphotectonics is controlled by the regional slope of the area. These Nalas form part of the Hapatkhai Nala sub-basin, which flows roughly in a N-S direction, and its trend is controlled by the Panjal and its subsidiary thrusts. Morphometrically, the Dudran and Baga Dudran Nalas form 3rd and 4th order drainage channels, locally corresponding to Trellis patterns.

The area around Dudran is mainly occupied by high mountains and ridges running in an E-W direction, separated by steep ravines and gorges. The maximum and minimum altitudes above m.s.l. are 3,513 and 1,600 m. respectively. Slope angles are as much as 60° and they are usually covered by shrubs and scree materials.

The area mapped lies in the Rampur-Apharwat section of the Salkhalas in the Pir Panjal Range and is encompassed in between lat. $34^{\circ}4' - 34^{\circ}8'$ and long. $74^{\circ}11' - 74^{\circ}15'$, as shown in the Survey of India Topo sheet No.43-J/4.

The granite body has been called as the Dudran granite after the name of the village nearby and has been referred to as such in the following discussions. The exposure of the granite is roughly 2 kms. x 1 km. (pers. comm. Ansari, 1977), in area and the region between the Dudran and Baga Dudran Nalas was studied. Access further to the south, where the granite is seen to continue, was not possible due to strategic reasons. The Dudran granite occurs as a sheet like body in bands of varying thickness. Bounded to the east and west by Salkhala metasediments, it has a concordant relationship with the latter. Granites are exposed in the Nala cuttings, where steep walls are made up of these rocks. Exposures are also seen on the peaks and slopes of the ridge separating the Dudran and Baga Dudran Nalas, as well as on the ridges flanking them.

Previous Work :-

The Salkhala Schists (in which the granite under study intrudes), of the central Himalayas are characterised by the presence of granitic intrusions ranging in size from small stocks to large batholitic masses. The Salkhalas of Precambrian (?) age were first studied by Middlemiss (1911); he grouped the Salkhalas in the Slate Series of Hazara. Bion (1928), while recognising these rocks as older Palaeozoics failed to report the Purana elements present in them. It was, however, left to Wadia (1928) to distinguish the Salkhalas as being inherently different from the Slate Series and to group them into a separate rock formation of Precambrian age. He described the constituent elements of these rocks (Wadia, 1931), and gave a generalised account of N.W. Kashmir, (Wadia, 1934). The succession met with in the area as propounded by Wadia (1934), and still accepted, is as follows:-

Karewas	Recent to sub-recent
Granites	Eocene
Limestone	Triassic
Panjal Traps and Agglomeratic Slates	Upp. Carb. to Permian
Tanawals	Mid. Carb.

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Muth Quartzite	Devonian
Slates, quartzite	Ord. to Sil.
Fossiliferous clays, limestones, sandstones	Cambrian
Salkhalas	Precambrian.

Wadia (1928, 1934) has reported the presence of biotite granite from the Hapathkhai Valley of Uri Tehsil, in Baramulla district.

Kaul (1976), discussed the stratigraphy of the Buniyar area and has classified the rocks into the following litho-units:

Arenaceous phyllites

Quartzite-phyllite intercalations

Intercalatory bands of quartzite and quartzite schist.

Limonitized quartz-sericite-chlorite-schist.

Phyllitic slates with intercalations of arenaceous phyllites.

Quartz-sericite-phyllite intercalations of phyllitic slates.

These units are believed to have an intercalatory nature and are said to repeatedly merge within the sequence. Kaul (1976) has reported the occurrence of an intrusive granitic body of quartz-monzonitic composition near Dudran, which is also believed to be the source of the polymetallic sulphide mineralization reported in the area. Raina (1977), while dealing with the mineralization of the Duniyar area has also attributed their source to the Dudran granite. Acidic sills and dykes, now metamorphosed to quartz-chlorite-sericite-schist are exposed at a number of places. Quartz veins also show a profuse distribution.

Apart from these few references, a review of available literature shows a marked absence of any studies on the Dudran granite. However, the Jammu and Kashmir State Directorate of Geology and Mining and the Geological Survey of India have been engaged in mapping the area, with yet meagre information on the granites.

The age of the Salkhalas and the granites intruding them have been a subject of controversy ever since Wadia (1928), first placed them in the Precambrian. This he had done on the basis of their sharp and thrusted contact with the different lithologies of the Dogra Slates; yet he further drew attention to what seems to be two transitional and conformable junctions (one in the Kishenganga gorge and the other in the Tangdhar valley), with the fossiliferrous Cambrians. If this be true, then the Salkhalas are definitely younger than earlier conceived by him. Kaul (1976), on the basis of a lower metamorphic grade in the Buniyar area, also assigns a Pre-Silurian age to these rocks. Yet, the similarity in the lithological assemblage and degree of metamorphism had prompted Pascoe (1950) to correlate the Salkhalas with the Jutogh and Chail (Precambrian age) Series of the Simla Himalayas. He, (Pascoe, 1950), further points to a close general resemblance of the Salkhalas with the Dalings of the eastern Himalayas, thus envisaging a continuous belt of Precambrian metasediments from one end of the Himalayas to the other. Krishnan (1968) also equates the Salkhalas with the Jutogh and Chail Series of Simla.

Discussing the granites, Wadia (1934) distinguishes between two types of granites intruding the Salkhalas; viz. the biotite granite and the hornblende granite; the former being older are foliated and form a part of the Central Gneiss facies; and the latter being non-foliated are younger. The granites are seen to be intruding not only the Salkhalas but also the much younger Tanawals (Permo-Carb. age). On their field relationship, he believes them to be of Eocene age (Wadia, 1934). Pascoe(1950), however, believes them to be of approximately Carboniferous age and on the basis of their contact metamorphic effects and lithological characters, has equated them with the Chor granites (late Paleozoic age) near Simla, which are intruding the Jutogh Series. Sharma (1974), believes the granites of northwest Himalaya to be late tectonic, emplaced during the last phase of Hercynian Orogeny following the Panjal Volcanic outburst, i.e. post-Permian in age.

Thus, from the above discussion, it is evident that nothing definite can be said regarding the age of either the Salkhalas or the intruding granites. At the present state of our knowledge, all that can be surmised, is that the Salkhalas range in age from the Precambrian to the Cambrian, possibly younger and the intruding granites are obviously much younger.

Scope of Work :-

The Salkhalas have formed a controversial topic ever since Wadia (1928), delineated them as a separate formation. While the discussion to date has centered around their age and structural relationship with the Dogra Slates on the one hand and the Tanawals on the other, a review of literature reveals little information about the granites found in the area. Earlier workers have restricted their studies to the metamorphics of the area with emphasis on their lithology and the mineralisation found in them, largely based on field observations; and neither the petrology of the Salkhalas nor that of the Dudran granite have been dealt with. In order to fill the gap in knowledge in this sphere, it was proposed to carry out systematic and intensive petrological studies on the granites and on the intruded metamorphites. The programme envisaged the deciphering of the various phases of the Dudran granite and to correlate the petrological studies with field observations and thus, to group the granites into combinations of genetically different types. Coalesced with geochemical studies it was hoped to use the petrological results in determining the origin and the mode of emplacement of the granites. The contact metamorphic effects and the resultant change in metamorphic grade as evidenced by wall-rock alteration and mineralogical changes is also sought to be brought out here.

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Chapter Two

GEOLOGICAL SET-UP

The various litho-units found in the area are believed to be of Salkhala and post-Salkhala age and structurally belong to the north-western limb of the Rampur-Apharwat Anticlinorium of the Pir Panjal Range (Wadia, 1934).

Intruding the Salkhalas is the Dudran granite with numerous quartz reefs, veins and stringers. (Fig. No. 1 shows the outcrop of the various rock types in the area).

Field work in the area has revealed that the rock types are mainly metapelites, intruded by the Dudran granite and permeated by quartz veins. Metamorphic grade is seen to increase as one approaches the granite, suggesting a magmatic origin for it. Thus, while at the contact, the schists are seen to contain anthophyllites, staurolites and chlorites, as one moves away from the granite, the grade of metamorphism shows a lateral gradation to quartz-sericite-schist to arenaceous and carbonaceous phyllites and finally the slates which have a regional occurrence.

The details of the litho-units mapped in the area are discussed below.

PHYLLITES :-

These are the most abundant rock types in the area and are in general arenaceous in nature. They are exposed both to the east and west of the granite. Regionally the rocks show change in the grade of metamorphism from slates in the west to phyllites in the east. The phyllites are soft and friable. However, as one approaches the granite, the resultant increase in the degree of induration, due to silicification, has made them hard and massive. The characteristic phyllitic sheen observed at the surface is due to the parallel arrangement of tiny sericite flakes. The rock is light to dark grey in colour, thinly laminated and readily cleavable along the foliation planes. The bands of phyllites show the abundance of sericite flakes in contact with quartz-schist bands.

The general strike of the phyllites ranges from N-S to NE-SW dipping at steep angles (60°-70°). The phyllites exhibit two generations of folding (F_1 and F_2). The first foliation (associated with F_1) is parallel to the compositional banding of the phyllites. The second foliation in these rocks trends in a NW-SE direction and dips steeply to the west. Effects of deformation are seen in the development of kinks (chevrons) and small to intermediate scale, moderately plunging and steeply inclined, gentle folds, with amplitudes and wave lengths of a few cms.

Extensive jointing is noticed with as many as three sets of joints present. The first set of joints (J1; strike E-W; dip 65°S) developed prior to first folding (F_1); these joints are observed to be folded alongwith F_1. The second set of joints (J_2; N70°W/ 37°S) displaces the first fold and was apparently formed after F1 and prior to F_2. The attitudes of the third set of joints is N-S/38°W.

Under the microscope, these rocks are seen to have a 'salt and pepper' texture. It comprises of quartz, sericite, chlorite and opaque ores. The total amount of phyllosilicates is seen to exceed 50%. Next in abundance is quartz. The quartz grains in a few samples are seen to have sutured margins, indicating crushing of the rock. Feldspars, in general are subordinate to quartz and the phyllosilicates. Though, commonly untwinned, a few grains of plagioclase feldspar show polysynthetic, glide twinning of secondary origin.

SCHISTS :-

As one approaches the granite, contact metamorphism is seen to have transformed the phyllites into schists of varying composition. These are seen to occur in a narrow band ranging in width from 10 to 30 m. at the contact with the granite. While they are present towards the western contacts of the granite, the schist are seen to be conspicuously absent towards the east, where granites abut against phyllites.

The presence of phyllite on the eastern contact, indicating a low grade of metamorphism, may be attributed to the westerly dip of the granitic sheet. Xenoliths and patches of schists are found occurring in the main granite body, which may indicate that the granite is younger in age and intrusive into the schists (Fig. No.2 shows the photograph of a schistose xenolith).

The schist in general is soft; fine to medium grained; showing anisotropic fabric manifested by lepidoblastic structure of sheet minerals and slight elongation of quartz grains. It is dull white to grey in colour. In the area under study, mineralization in the schists is seen in the form of specks and disseminated grains of galena, sphalerite and copper ores.

The general strike of the schists parallels the strike of the phyllites, i.e. N-S to NE-SW, with steep dips. Atleast two sets of joints are seen, at right angles to each other. Jointing is most conspicuous in the schistose patches flanked by granite. The trend of the joints varies from E-W to NE-SW.

Fig. No:2 Schistose xenolith in monzogranite

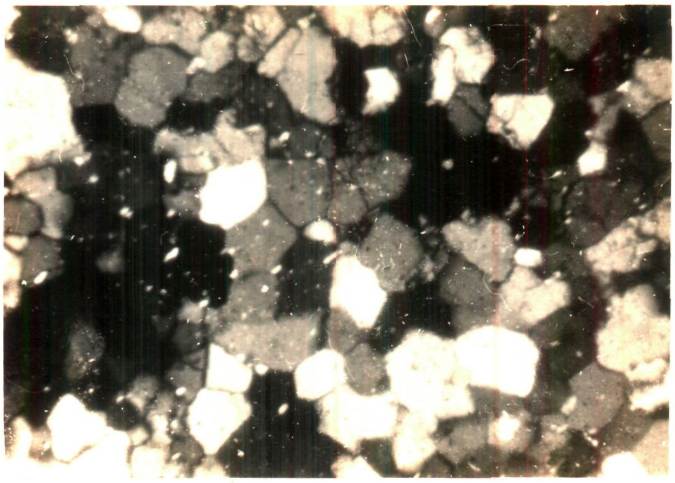

Fig. No 3. Equigranular quartz grains, exhibiting recrystallization in schists.

In thin sections, the schist shows mica flakes and anthophyllites arranged parallel to the schistosity planes. Quartz and feldspar grains show elongation parallel to the regional foliation of the rock. The effects of multiple deformation are seen in the schists in the nature of atleast three sets of foliation planes trending at angles of 25° to 40° to each other. The quartz grains exhibit equigranular mosaic, thus indicating recrystallization (Fig. No.3). The quartz grains are elongated and show directional parallelism with schistosity. K-feldspar occurs as large porphyroblasts and are cut through by biotite flakes along cleavages and fractures in the grain, suggesting a later origin of biotite. Micas and chlorites exhibit lepidoblastic texture parallel to schistosity. The micas are seen to be wrapping around larger quartz and feldspar grains yielding a pseudo-augen texture. Calcite grains occur as xenomorphic crystals with typical twinning and intersecting cleavage planes. Staurolites and garnets occur as large porphyroblasts. The plagioclases are in general untwinned. However, in some sections abundant poly-synthetic glide twinning is observed. In a single grain, twinning is multiple with essentially equal lamellar thickness. Individual lamellae are slender and often show termination within the crystal as long tapering points which are localised, presumably in areas of greater stress. The twins, thus, fall in Type 'A' of Gorai (1951). Vance (1961), considers them to have a secondary origin and has suggested that the development of glide twinning is the result of stress acting on the rocks. The generally untwinned nature of the plagioclases can be attributed to coalescence of twinning. With increased deformation, twin lamellae may coalesce and assume an untwinned appearance (Vance, 1961). The fairly large number of untwinned plagioclase crystals in the schists can be attributed to the loss of twinning by coalescence due to intense deformation and recrystallization (Barth, 1969). Turner (1951) and Gorai (1951), have observed that plagioclases of metamorphic rocks are untwinned or only slightly twinned. The plagioclases in addition, to being untwinned are in general anhedral, unzoned and irregularly bounded with interlocking grains of unequal sizes, revealing an inequigranular texture.

Schists of varying mineral compositions, in the contact aureoles, are observed fringing the granites. The width of the aureoles ~~is~~ not found to exceed 30 m. Two zones of contact metamorphism have been deciphered in the area:

a) Outer zone :-

In the outer zone of the contact aureole, pelitic assemblages include various combinations of quartz, muscovite, biotite, anthophyllite, staurolite and plagioclase feldspars. The staurolite is prominently developed in the outer zone of the contact aureole.

b) Inner zone :-

Rocks of distinctly higher grade border the western margins of the pluton and form a narrow band around the contact. The mineral assemblages are more complex then in the outer zone and include various combinations of quartz, biotite, muscovite calcite and corundum. The presence of Corundum indicates internal disequilibrium (Turner, 1968). The rocks of this zone point to a higher grade of contact metamorphism.

GRANITES :-

Wadia (1928), first reported the presence of a biotite granite in the area. The granites occupy an area of 2 x 1 km. (pers. comm. Ansari, 1977), and are emplaced in the Salkhala metasediments along foliation planes. The schists are exposed at the western contacts, whereas phyllites form the eastern margins (Fig. No.1.).

That the Dudran granite is a subjacent, sheet-like intrusive, which broadens out downwards is revealed by the greater outcrop width at lower levels where erosion has exposed its roof cover; and lesser outcrop width at higher elevations where erosion has not progressed so far. There is no evidence about its base. Intrusion along the foliation planes of the older rocks has resulted in the contact at places being warped and bulging into the older, Salkhala metasediments.

Field studies have revealed the presence of three types of granites in the area, viz; A) Spotted granite; B) Foliated granite; and C) Non-foliated granite.

A) Spotted granite :-

The granite lies in the centre of the area and is massive, medium to fine grained and whitish in colour. The rock shows clusters of ferromagnesian minerals which give it a spotted appearance. The rock is highly jointed, with as many as four sets of joints present. It shows a marked absence of xenoliths of anykind, and this alongwith the maximum jointing undergone by it, points to the fact that the Spotted granite is the oldest rock in the igneous regime of this area.

B) Foliated granite :-

This type occupies a major part of the exposed outcrops of granite, and is also present within the central portions surrounded by the non-foliated variety. The granite is in general dark coloured, coarse, with a porphyritic texture. The rock shows strong mineral lineation with mica flakes oriented in a preffered direction (parallel to the strike); feldspar and quartz grains alternate with the mica bands. The rock is in sharp contact with quartz-sericite-schist at the western margin and the foliation of the granite is seen to parallel the strike of the schist. The rock is well jointed with atleast three sets of joints present; those trend from N-S; NE-SW and NW-SE.

A chilled margin is seen at the eastern contact with the phyllites. Grain size is observed to increase as one moves away from the contact. The chilled margin is about 5 cms. wide. Xenoliths and patches of phyllites are found to occur in the foliated granite.

c) <u>Non-foliated porphyritic granite</u> :-

The rock lies in contact with the foliated granite and also encloses the Spotted granite (Fig. No.1). It is finer grained than the foliated granite and is light to buff coloured. At places, in contact with the foliated type, weak foliation is discernible; however, in general the rock is massive with no visible parallel arrangement of minerals. The weak foliation, mentioned earlier, could most probably be due to the contact effects (Balk,1937). The rock has a porphyritic texture, with the phenocrysts of feldspars being as much as 2 cm. in length. Profuse quartz veins are present and the granite appears to be coarser in contact with them. Two sets of joints are recognised.

AGE RELATIONS OF THE GRANITES :-

Several xenoliths, both foreign as well as cognate have been recognised, not only in the margins but also in the central portions of the Foliated and Non-foliated varieties. However, no xenoliths are found in the Spotted granite.

All foreign xenoliths without exception comprise the schist and phyllites belonging to the Salkhala series. They vary in size from irregular patches measuring less than .5 sq.cm. to as much as 1 m. (long axis). In some phyllitic inclusions, the original sedimentary characters such as colour and compositional banding are seen. It has, however, been noticed that inclusions generally occur in concordant positions, with individual xenoliths showing hardly any variation in their attitudes; at places, however, slight discordance is noticed. Generally, the contact between the xenoliths and the enclosing granite is sharp, indicating a low-temperature of the magma. The presence of xenoliths in Foliated and Non-foliated granite suggests a magmatic origin for these rocks (Fig. No.4). The fact the foreign xenoliths, without exception, are made up of Salkhala metasediments goes to prove that the roof cover of the Dudran granites must have been made up of rocks belonging to the Salkhala series.

In addition to the foreign xenoliths, several xenoliths of fine to medium grained foliated granite occur within the non-foliated variety; generally with sharp as well as fused margins. These xenoliths range in size from less than 10 cm. to more than 5 m. in length (long axis). The presence of xenoliths of Foliated granite in the Non-foliated porphyritic granite indicates that the latter is of magmatic origin and is younger than the Foliated granite.

The age of the Spotted granite could not be ascertained in the field because of the limited extent of the outcrop and the absence of xenoliths. However, the presence of four sets of joints in the Spotted granite as against two and three sets in the Foliated and Non-foliated granites, respectively, may point to its older age. This is further

Fig. No. 4 Xenolith of schist in quartz-diorite

Fig. No 5 Intrusive contact of quartz-diorite with the Salkhala metasediments.

supported by the metamorphic effects, due to later intrusion, which has resulted in the development of spots on these rocks.

Apart from the above, a xenolith of a gneissic member, not found in-situ in the area, is also found in the non-foliated granite. This gneiss probably occurs at depth, which may have been caughtup by the upward movement of the granitic fluid.

Nature of Contact :-

The granite is framed all around by rocks belonging to the Salkhala series and is no where in contact with other lithounits. The contact of the granite with the Salkhala metasediments is sharp (Fig. No.5), indicating the magmatic origin of the granite as well as the low temperature of the granitic liquid. Across the strike, when the granite is traced eastwards and westwards, it passes into the Salkhala Schists and Phyllites without any tectonic disturbance or discordance. The contact is parallel to the foliation trend in the granite, as well as to the strike of the surrounding Salkhala metasediments. This parallelism is, probably, due to the intrusion of the granite along the foliation plane of the metasediments.

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Chapter Three

PETROLOGY OF THE GRANITES

The granitic rocks of Dudran were first recognised by Wadia (1928, 1934), as a biotite granite; he however, did not attempt any petrological studies on these rocks. Kaul (1976), later recognised these rocks to be of quartz-monzonitic composition.

In the present investigation, granitic rocks exposed along the Dudran and Baga Dudran Nalas, and the area in between were systematically sampled and studied. Determinations of the mineral compositions and their relative abundance in the three granite

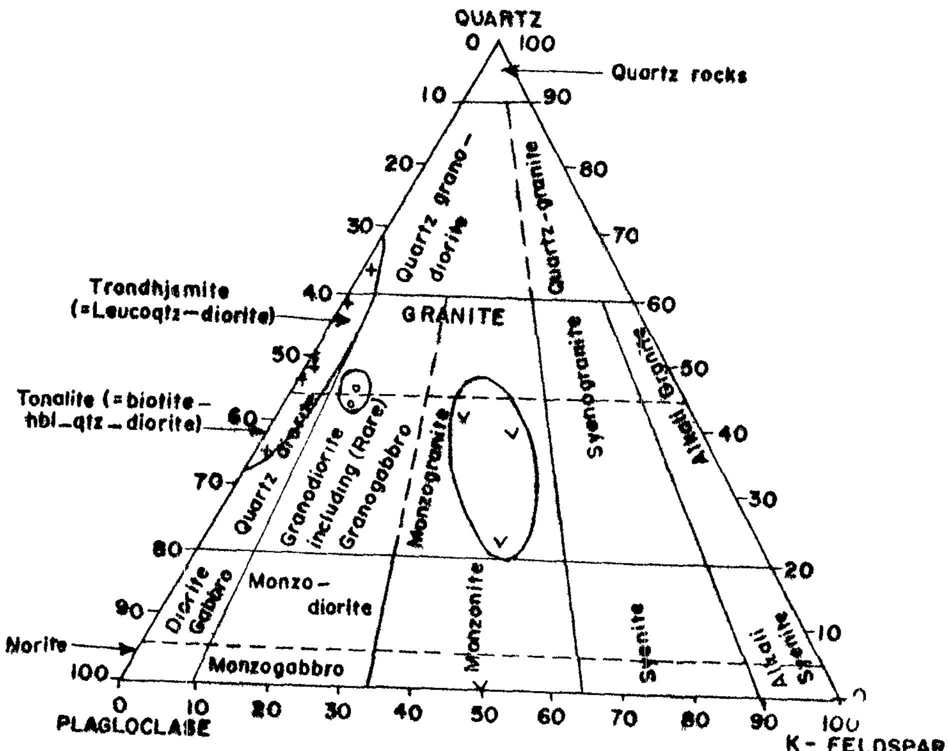

Fig. No. 6 : MODAL QUARTZ-PLAGIOCLASE-POTASH FELDSPAR DIAGRAM OF DUDRAN GRANITES. (Superimposed on Streckiesen's (1964) Classification Scheme) (Symbols as in Fig. No. 1.)

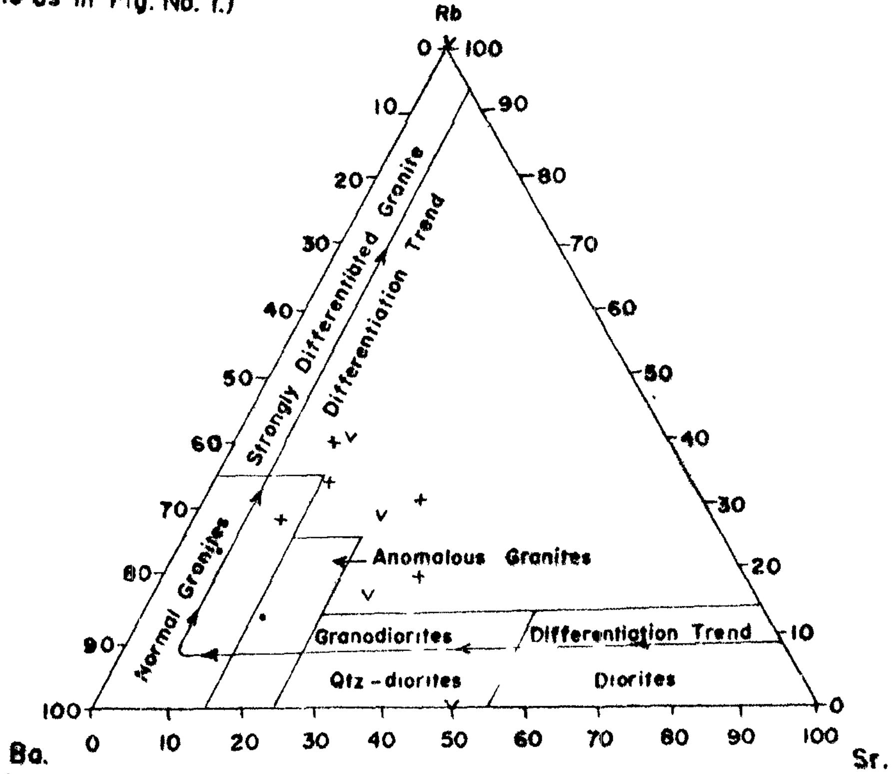

Fig. No. 21 : DIFFERENTIATION TRENDS OF DUDRAN GRANITES.
Figure after, El-Bouseilly & El-Sokkary (1975) (Symbols as in Fig. No 1.)

types was carried out to differentiate and classify the various granite types. The thin sections were stained according to Bailey and Stevens (1960) method. Individual slides were first etched by concentrated Hydro-fluoric acid and then dipped into a solution of Sodium-Cobalt-Nitrite. As a result K-feldspars were stained yellow. After staining the slide, modal compositions of the three types of granites were determined by the point count method of Chayes (1956). An average of 1,000 points were counted in all the three rock types.

While the three types of granites, in general, have similar mineral compositions; differences in the relative proportions of various minerals are very obvious. The average modes of the three granites are presented in Table-1. The modal Quartz- Plagioclase feldspar- Potash Feldspar (recalculated to 100%) were plotted on a ternary diagram, superimposed on Streckeisen's (1967) classification scheme (Fig. No.6).

The plots of the Spotted granite are confined to within a narrow zone in the Granodiorite field; this suggests a compositional uniformity. Wide dispersion of plots of the Foliated granite is very evident from the diagram. Most of the plots lie on or near the Quartz-Plagioclase tie line. They range in composition from Tonalite-Trondhjemite to Quartz granodiorite. The great variability in composition may be attributed to the metasomatic effect associated with later granitic intrusion. All the points for the Non-foliated porphyritic granite are confined to Tuttle and Bowens (1958) low-temperature trough (Fig. No.6), in the Monzo-granite field, thereby indicating a purely magmatic origin.

A) Granodiorite (Spotted granite) :-

This type is believed, on the basis of field characters to be the oldest granite in the local kinematic regime. It has the smallest outcrop and is restricted to the central portions of the area. The overall texture of the rock is hypidio-morphic granular. It is medium to fine grained and is whitish coloured. The rock shows clusters of ferromagnesian minerals, which give it a spotted appearance.

Plagioclases are the major minerals present and constitute about 33% to 41% by volume of the rock. It is generally euhedral and well twinned. Both fresh to highly altered grains rich in sericite and epidotes are found and it is liberally sprinkled with biotite flakes. K-feldspar, subordinate to plagiocalse, has a modal range of 6% to 7%. It is usually present in irregular, interstitial grains of various sizes, sometimes exhibiting poikilitic texture. Gridiron twinning is a common feature of the alkali feldspars.

Quartz occurs as irregular masses with crystals of varying sizes and ranges from mosaiced grains with undulatory extinctions to granulated, slivered aggregates. Next to plagioclases, it is the most common mineral phase in the rock, occupying 29% to 30% of the rock.

The micas have a modal range of 10% to 27%. Biotite, which is the major mica present, forms ragged to slivery patches. Alteration of biotite to chlorite is common. Many crystals are seen to contain droplets of sphene and needles of rutile (?) concentrated along cleavages. Birdseye structure is commonly observed. The biotites enclose the older feldspar and occurs in the rock as irregularly distributed clusters, imparting it a spotted appearance. The development of biotite as clusters may be attributed to the metamorphic effects associated with later intrusions. The volatiles from the younger granites probably facilitated the migration of ferromagnesian constituents to the favourable sites of nucleation at which the growth of biotite crystals was concentrated.

Metallic opaques and calcites are the common accessories present. While the metallic opaques are dispersed in the rock, calcite occurs as stretched veins in the K-feldspar.

B) Quartz-Diorite (Foliated granite) :-

This is the most abundant rock in the area. It is in general darker in colour, coarse and foliated showing porphyritic texture with phenocrysts of feldspar and quartz alternating with mica band. Micas are flaky and fill the interstices, yielding strong mineral lineation.

The feldspars are the major mineral phases present; K-feldspar is absent or is present in very minor amounts. It has a modal abundance of 0% to

1%. The few K-feldspars present are microclines with characteristic grid twinning discernible. The plagio-clases have a modal range of 24% to 56%. Elongated plagioclases are a common feature. They range in composition from Oligoclase to Andesine. The Ande-sine bearing varieties of this type may be termed as Calcic-Trondhjemite (Davis, 1963).

The rock as revealed by the modal abundance of quartz from 33% to 45% is silica saturated. Quartz forms large anhedral patches. At places quartz shows well developed crystal outlines. Minute thread like inclusions of Rutile are seen. These have a prismatic form. While, the mineral generally shows wavy extinction; subhedral crystals are seen to have straight extinctions.

The micas have a modal range of 2% to 20%. Biotites are preponderant over muscovites, and are present as lamellar aggregates and yield the linear character apparent in hand specimens. The plates of micas are seen to enclose the older plagioclases. The bent plates have wavy extinctions. Inclusions of zircons are present in the biotites.

While epidotes are common in the quartz diorite, they are seen to be conspicuously absent in the sample from the chilled zone near contact with the Salkhala metasediments.

The accessories include zircon, rutile, and opaque ores.

c) <u>Monzogranite (Non-foliated porphyritic granite)</u>:-

This is a medium to fine grained rock and has a hypidiomorphic granular texture illustrated by inequidimensional grains of feldspars (K-feldspars and plagioclases) and interstitial grains of quartz. Micas are subordinate to both quartz and feldspars, and occur as flaky masses arranged in a roughly linear pattern.

Crystals of K-feldspars occur as large phenocrysts, they have irregular shapes and are usually subhedral. They have a modal range of 23%. to 37% and occur as microcline microperthites. The majority of microclines show cross-hatched twinning, indicating that they are secondary after orthoclase (Heinrich, 1959; Barth, 1969). Some small crystals of

K-feldspar do not show any cross-hatched twinning and are probably orthoclase. The presence of both microcline and orthoclase indicates disequilibrium and may be attributed to relatively rapid cooling. Both the alkali feldspars contain scattered and irregular patches of plagioclase forming micro-perthite. The phenocrysts are set in a matrix composed of micas.

Plagioclases, which have a modal content ranging from 24% to 34% are seen as euhedral crystals with well developed crystals outlines. They are commonly albite to oligoclase in composition. Some crystals show normal zoning, with the calcic core often being intensely altered to sericite. Perthitic relationship with the K-feldspars is a common feature.

Quartz has a modal range of 21% to 35%. It occurs as anhedral to euhedral crystals (the latter are more common). It is found interstitial to larger feldspar grains (Fig. No.7); shows a sutured contact with each other and forms an equigranular mosaic. The strong undulatory extinction of quartz

Fig. No. 7 Intersertal quartz between phenocrysts of K-feldspars in monzogranite

Fig. No 8. Deformed and bent biotite plate, showing wavy extinction in monzogranite crystals is believed to indicate post-crystallization deformation.

The micas, commonly biotite with some muscovite, (modal range 6% to 14%), are subordinate to both quartz and feldspars. They occur in aggregates, often with bent plates which show a wavy extinction (Fig. No.8). In some sections the biotites are linearly arranged, parallel to the contact with the foliated granite. This is believed to be due to the contact effects of this granite (Balk, 1937). In some of the thin sections of these contact rocks, the biotite is seen to be wrapping around the feldspars (microclines) which are roughly circular in shape.

The accessory minerals include zircon and apatite. Epidotes are also common to all sections. Apatites and epidotes have probably formed by the breakdown of calcic plagioclase.

PLAGIOCLASE TWINNING :-

The genesis of a rock may be revealed by the nature and type of twinning exhibited by the Plagioclases. Gorai (1951), Turner (1951), Vance

(1961), Tobi (1962), Seifert (1964), etc. believe that plagioclases of igneous rocks have a genetic history entirely different from that of metamorphic plagioclases.

The formation of a plagioclase twin has been attributed to various factors; Buerger (1945), believes that the rate of crystal growth is the principal controlling factor in the formation of a twinned plagioclase. Vance (1962), Smith (1962) and Seifert (1964) among others attribute this differential growth to the disturbance of crystal structure in response to the physicochemical environment and which, varying with time, is primarily controlled by temperature, pressure and chemical composition.

The frequency of twins is related to the grain size; larger crystals are generally more twinned (Gorai, 1951), Smith (1962), found that twinning in euhedral crystals is more common than in anhedral ones; he further believed that it is the existing environmental conditions and the rate of crystallization which control the frequency of plagioclase twinning. Earlier, Donnay (1940, 1943), Gay (1956), Smith (1958) and Vance (1962), had related abundance of plagioclase twinning to plagioclase composition and thus, its being structurally controlled.

Gorai (1951), divided the various twin laws into two groups and has differentiated the igneous and metamorphic plagioclases on the basis of the frequency of twin types. His two groups are as follows:-

A-Twins:- These are found in both igneous and Metamorphic rocks. This group includes the usually lamellar albite, acline and pericline twins, alone or in combination. Secondary glide twins, formed due to deformation by external forces after the growth of the crystal, are also classed as 'A' twins.

Vance (1961), has concluded that the polysynthetic twinning in plagioclase represents both primary growth and secondary glide twins. He has further developed morphological criteria to distinguish between the two. These include complexity of twinning, number and thickness of lamellae, and termination of lamellae. Bending and termination of lamellae as long, fine tapering points is believed to suggest secondary twinning. This view is also supported by a number of authors including Gorai (1961), and Turner (1951). Flehmig (1977), opined that the occurrence of polysynthetic twinning in a rock indicates rapid crystallization after nucleation and is thus of primary origin. However, several workers differ with Folhmig; they believe that most if not all, polysynthetic twinning is secondary (Emmons and Gates, 1943; Emmons and Mann, 1953; Kohler, 1949a; and Barth, 1969, etc.).

<u>C-Twins</u> :- These twins are restricted to the magmatic (both volcanic and plutonic) rocks. These include Carlsbad, Albite-Carlsbad, and Penetration twins, which are inferred to have formed in the crystals during growth. Significant amounts of C-twins are characteristic of undeformed igneous rocks. This amount is, however, dependant on th An-content of the plagioclase; Calcic plagioclase having, in general, more C-twins than Sodic plagioclase.

The untwinned nature of the plagioclases has been attributed to coalescence of twins. Barth(1969), states that twinning in plagioclases may be lost by

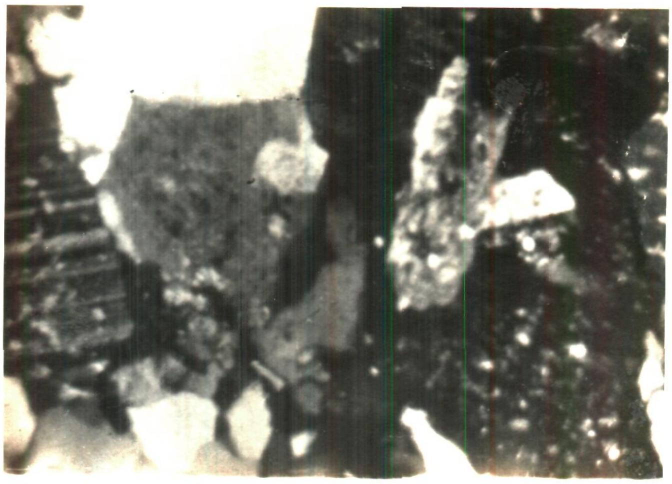

Fig. No. 9. Interpenetration plagioclase twin in quartz-diorite

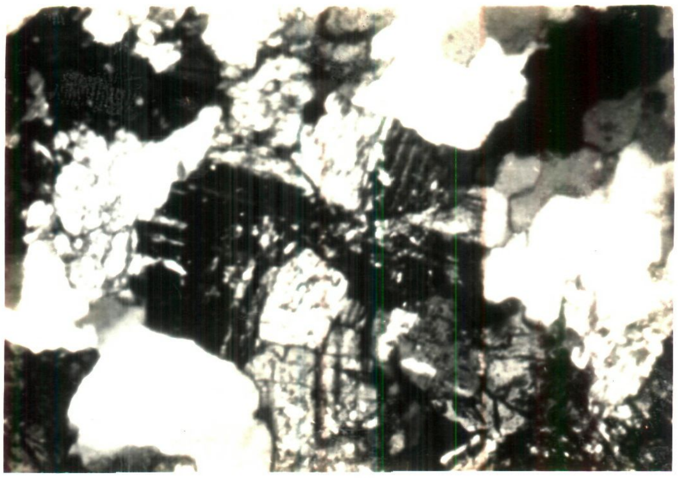

Fig. No 10 Interpenetration plagioclase twin in monzogranite.

recrystallization and intense and continued deformation. With increased deformation, twin lamellae may coalesce and assume an untwinned appearance (Vance, 1961).

While deformation twins are a common feature of all the granite types in the area, they are nowhere in excess of C-twins, thus, indicating that all the three granite types have a magmatic origin. Also, the presence of interpenetration twins in quartz-diorite (Fig. No.9), and in monzogranite (Fig. No.10) proves their magmatic origin. Fracturing and displacement of twins (Fig. No.11), often to the extent of seemingly twisted by a later phase of deformation (Fig. No.12), is seen in samples of Quartz-diorite. This may indicate that this granite is an earlier intrusion which has undergone deformation after crystallization. Also the presence of chess-board albite indicates that the feature was acquired during post-tectonic annealing conditions (Barth, 1969). It also indicates that the foliation in the granite is a later and assumed phenomenon, and is not a primary igneous feature.

A feature often observed in the Quartz-diorite is the presence of 'large steps' on the compo-

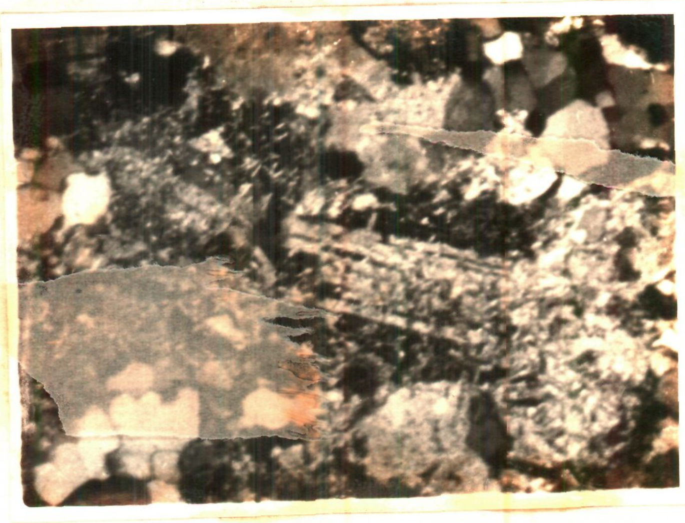

Fig. No. 11: Fractured and displaced plagioclase twin in quartz-diorite

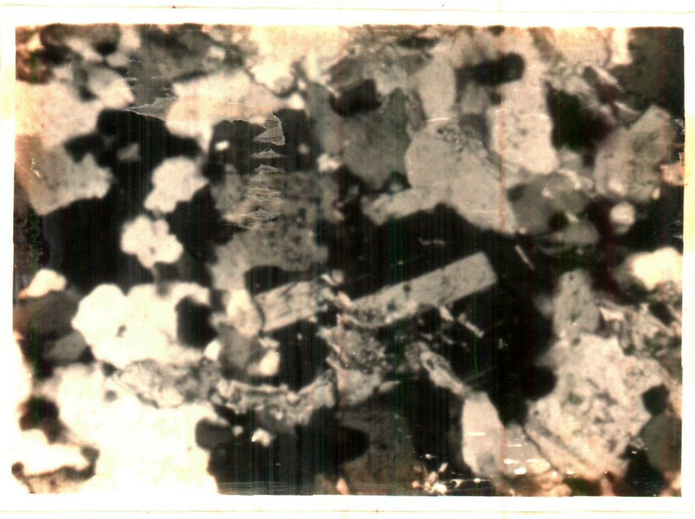

Fig. No 12: Deformed and "twisted" plagioclase twin in quartz-diorite sition faces of polysynthetic twins. Seifert(1964), has reported similar features in the Nonewaug Granite and has interpreted them as relict crystal growth features. Often those are found as opposed pairs and are inferred to have formed as the result of lateral motion of crystal during growth (Seifert, 1964).

The frequencies of A- and C-Twin types and untwinned plagioclases were determined for each rock type using Gorai's (1951) method. An average of 100 to 150 grains were counted in each section. In consistence with Gorai's (1951) observations it has been seen that the smaller plagioclases as compared to the larger plagioclases, are relatively untwinned. The plagioclase composition in the three granite types are fairly uniform. The average frequency of the A-C-twin and untwinned plagioclases in the rocks is shown in Table-II.

TABLE - II

Average frequency of A,C twinned and untwinned plagioclase

Granite type	% A	% C	% Untwinned
Granodiorite	24.13	62.23	13.64
Quartz-diorite	21.98	56.74	21.28
Monzogranite	23.85	59.73	16.42

The higher frequency of twinned plagioclases in the granites, as is clear from the above table, suggests a magmatic origin of the granites. Parsad (1968), has suggested that the twinning in plagioclases is lost following tectonic upheavals. The presence of insignificant amount of untwinned plagioclases in the three granite types indicates that the Dudran granite were emplaced after the uplift of the Himalayas had started.

HYPERSOLVUS OR SUBSOLVUS GRANITES :-

The subsolidus nature of the Dudran granite has been determined petrologically according to Parsons (1978) criteria. Tuttle and Bowen (1958), had classified rocks into subsolvus or hypersolvus on the basis of whether they contain plagioclase as a discrete phase or as perthitic intergrowths respectively.

In the crust, subsolvus granites are believed to be much more common than hypersolvus granites (Parsons, 1978). Tuttle (1952), pointed out the striking textural contrast between most hypersolvus and subsolvus granites; this was done on the basis of crystal outlines; thus in the hypersolvus granites, the crystal outlines are usually simple and show the crystal morphology; whereas in the subsolvus granites the grains have complex shapes and the crystal boundaries are commonly diffuse and exceptionally irregular. This difference is considered to be the result of major subsolidus recrystallization in the subsolvus rocks facilitated by the presence of volatile material during the cooling of the pluton. The hypersolvus character of the granite is preserved by the loss of volatiles during crystallization (Tuttle, 1952).

Parsons (1978), believes that the textural contrast between hypersolvus and subsolvus granites reflects the generally deeper seated nature of the latter and their potentially higher water content; and the usually reverse behaviour of the subsolvus granites.

The above enunciated principles were applied to thin sections of each rock type. It was observed that the hypersolvus-subsolvus nature is corroborated by the modal composition. The Quartz-diorite and the Granodiorite, are in general Hypersolvus, whereas the Monzogranites, with a higher content of hydrous minerals, is Subsolvus. This relation also indicates that the former varieties were emplaced in the Epizone. The presence of well developed foliation and chill margins may also indicate emplacement in the Epizone (Buddington, 1959). Likewise, the absence of these features alongwith the modal composition, plagioclase composition and solidus behaviour, all point to the Monzogranite having been emplaced in the deeper Mesozone.

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Chapter Four

GEOCHEMISTRY OF THE GRANITES

The behaviour and distribution of Trace Elements may provide some clues regarding the origin of Granites. During the crystallization of a parent magma, two types of crystallization behaviours have been considered by different workers: perfect equilibrium crystallization, where the solid is at all times in equilibrium with the melt; and perfect fractional crystallization, where only the surface of the crystal is in equilibrium with the melt. Trace element distribution during crystallization is also strongly influenced by the extent to which crystal and melt separate as crystallization proceeds (McCarthy and Hasty, 1976).

Considered alongwith certain Major Oxides, trace elements may be useful in determining the possibility of producing a granitic pluton (Condie, (1969). According to Taylor and Heier (1960); Taylor (1969); White (1966) and Vishwanathan (1972), the ratios K/Rb; Rb/Sr; Ba/Sr; Ba/K; Ba/Rb and K vs K/Ba; etc. are significant in this regard. In addition, the proportions of the trace elements with SiO_2 is also believed to be helpful in determining the nature of crystallization.

Analysis of the granites was carried out to ascertain whether the process of formation of the granites had produced a homogeneous melt or whether the granitic rocks that crystallized from the individual magma pulses were geochemically identifiable. This was determined by plotting the results onto a series of variation diagrams, the results of which have been subsequently discussed. These results confirm the conclusions reached on field observations and petrological studies, that in Dudran three different types of granites exist; that the three are

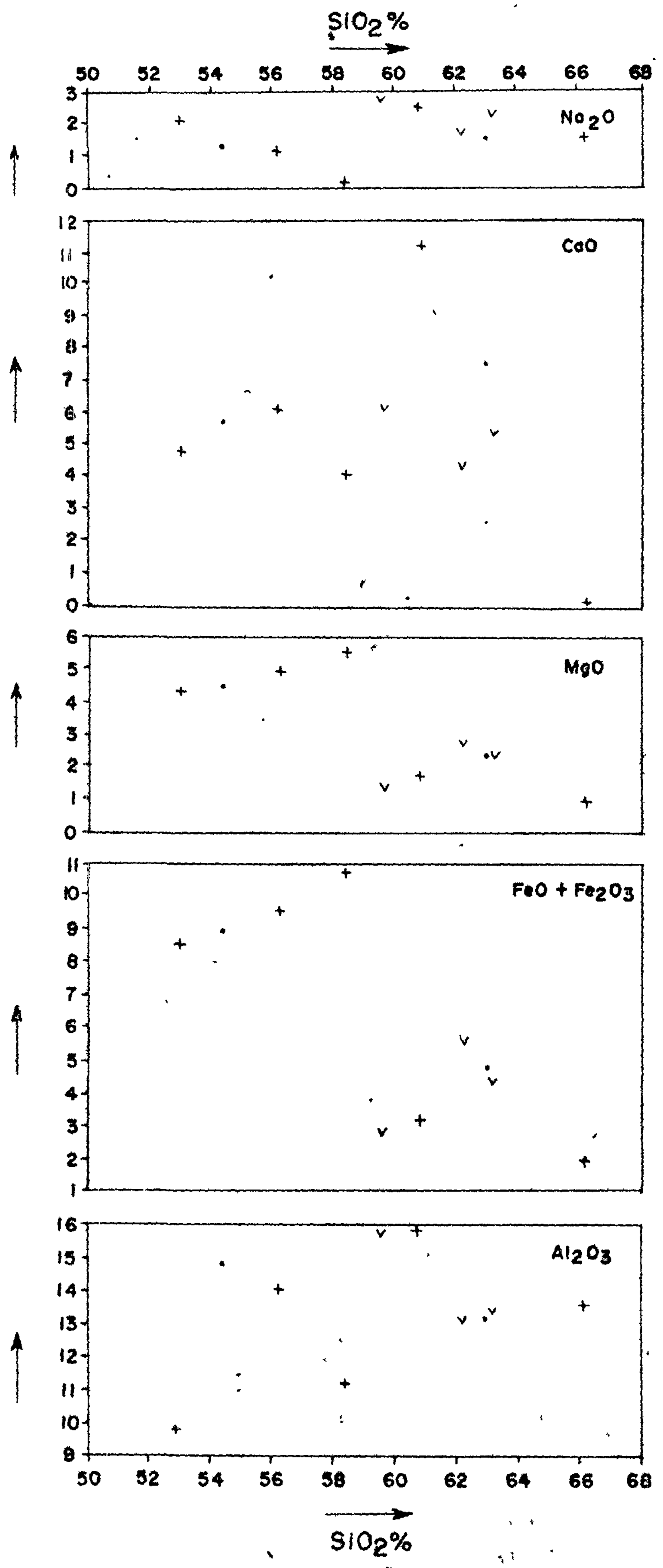

Fig. No. 13 : VARIATION DIAGRAM OF MAJOR ELEMENT OXIDES, CERTAIN TRACE ELEMENTS AND THEIR RATIOS, AS A FUNCTION OF THE SiO_2 CONTENT OF THE DUDRAN GRANITE. (Symbols as in Fig. No. 1.)

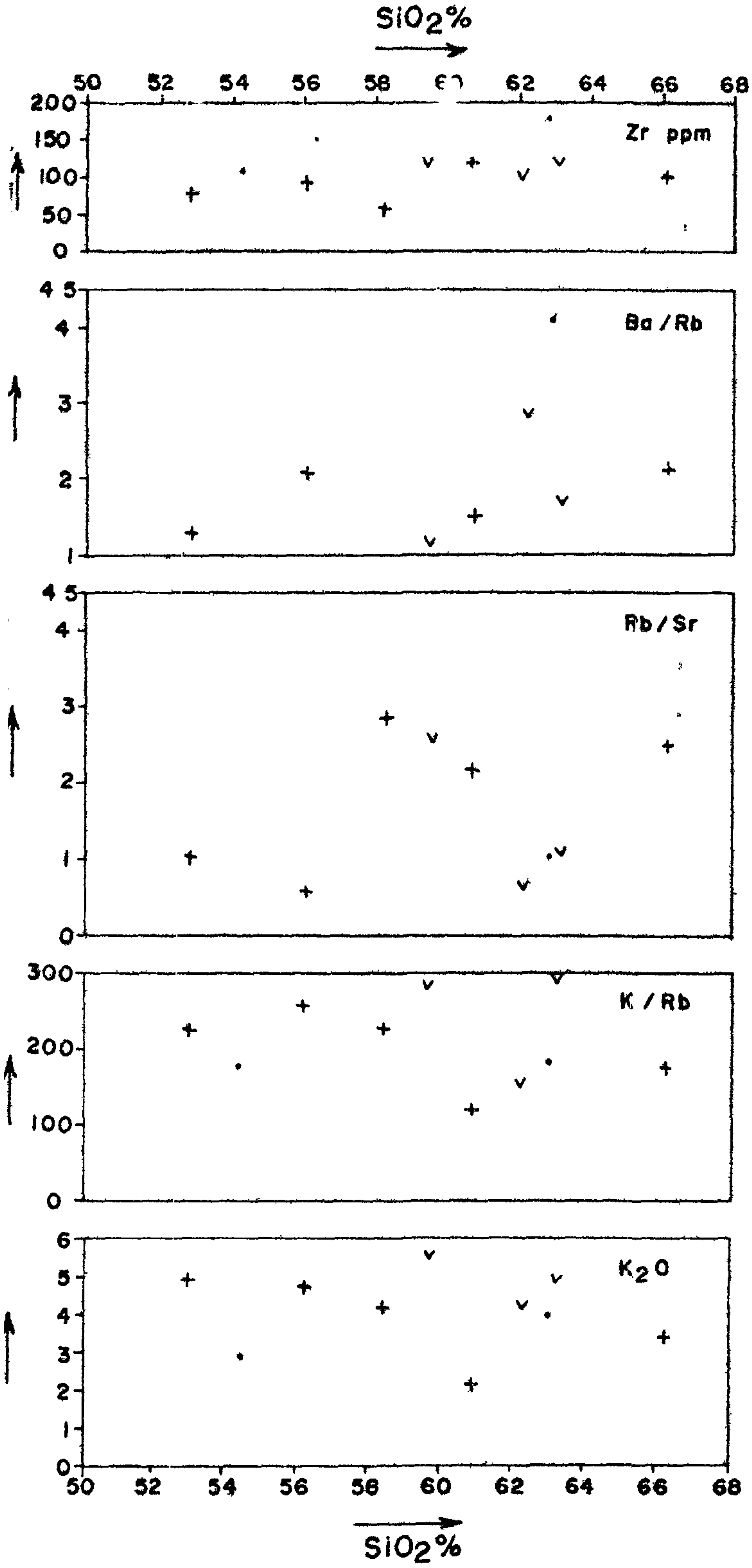

Fig. No. 13 : VARIATION DIAGRAM OF MAJOR ELEMENT OXIDES, CERTAIN TRACE ELEMENTS AND THEIR RATIOS, AS A FUNCTION OF THE SiO_2 CONTENT OF THE DUDRAN GRANITE. (Symbols as in Fig. No. 1) mineralogically different and as such are inherently geochemically separate and that the three belong to independent magmatic phases.

Geochemical interpretations have been attempted on all the three granite types. A total of 10 samples (5 from the quartz-diorite; 3 from the monzo-granite and 2 from the granodiorite; sampling is proportional to the area covered), have been analysed to determine their Na_2O and K_2O percentages, as well as their trace element concentrations. These results have been further augmented by recalculation from Modal abundances to determine the major oxides present in each rock type. The results of the analysis are presented in Table-3.

Major oxides :-

From Table-3 a marked variation in the concentration of the oxides and trace elements is discernible. This is most clearly apparent from the range of SiO_2 (recalculated from vol.%), from 58% to 66%. The various oxides plotted against SiO_2% on Harker's (1909) variation diagrams (Fig. No.13), do not reveal any systematic distribution of the plots for the different granites. Since, K-feldspar is

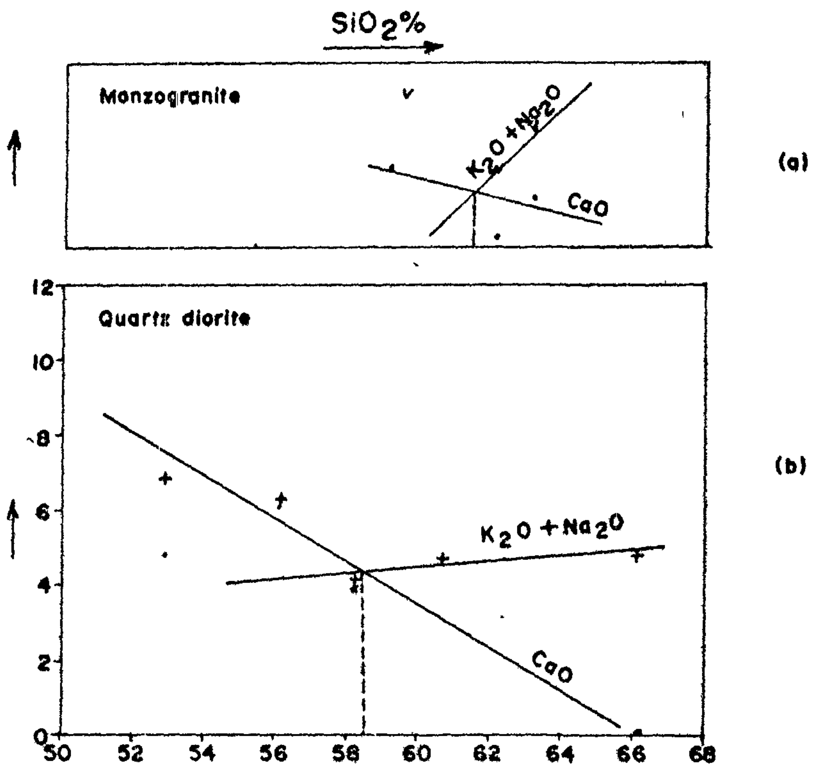

Fig. No. 14 : ALKALI – LIME INDEX OF QUARTZ DIORITES (b) AND MONZOGRANITE (a)
(Symbols as in Fig. No. 1.)

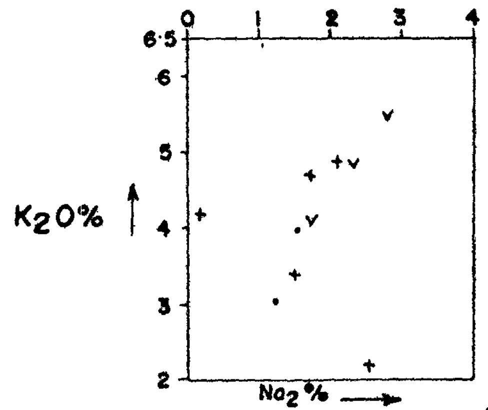

Fig. No. 15 : K_2O% PLOTTED AS A FUNCTION OF Na_2O% OF THE DUDRAN GRANITES
(Symbols as in Fig. No. 1.)

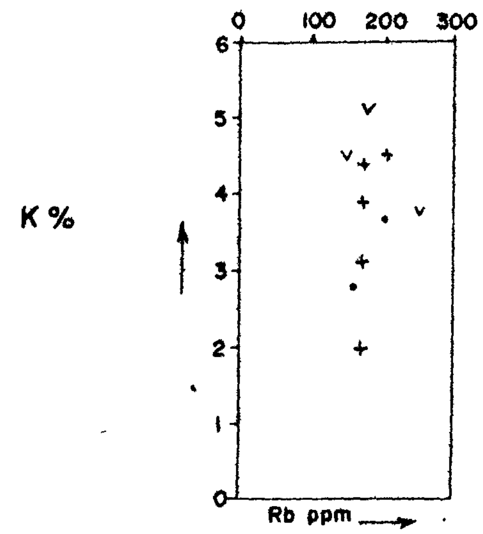

Fig. No. 16 : K% PLOTTED AS A FUNCTION OF Rb. CONCENTRATION OF THE DUDRAN GRANITES (Symbols as in Fig. No. 1.)

low or absent in these granites, the high K_2O values, in the three granites is a reflection of the high modal values of the Micas. However, since these rocks are not enriched in Na_2O it appears that, the plagioclases have not been strongly albitized. With increasing albitization Na_2O would be enriched, probably at the expense of K_2O as well as CaO (Crowder and Ross, 1973).

The Alkali Lime Index for the three granites was determined (Fig. No.14) and it was observed that the Monzogranite has an index of 61.4; placing it in the Calcic field; the Quartz-diorite has an index of 58.5, well in the Calc-Alkalic field. The index for the Granodiorite could not be determined.

When K_2O% is plotted against Na_2O% (Fig. No. 15), a linear trend is obtained for the monzogranite and the granodiorite, indicating an increase in K_2O% with rising Na_2O%. This is in accord with the earlier mentioned non-albitized nature of the plagioclases and the high modal content of the Micas. On the other hand the plots of K_2O% versus Na_2O% for the quartz-diorite reveal a varied trend, corresponding to the mineralogical composition of the granites.

Trace Elements :-

Rubidium, Barium and Strontium are believed to be widely present in acidic igneous rocks, where they are incorporated in the K-site of the K-feldspar lattice. Rb, Ba and Sr are plotted as a function of SiO_2 in Fig. No.13. SiO_2, in this and other figures has been used as a measure of the degree of fractionation of these granites. The three elements in the granodiorite show a steady rise with increasing SiO_2. On the other hand, while Rb declines in the monzogranite, it remains constant in the quartz-diorite. Similarly, while Ba rises in the monzogranite and the quartz-diorite; Sr shows an upward trend in the monzogranite; the trend is reversed in the quartz-diorite, with Sr abundance declining with rising SiO_2%. The decrease in Sr in the quartz-diorite is similar in trends as reported by Condie and Lo (1971), for the Louis Lake Batholith, U.S.A. and by Khalil, et al (1978), for the Holterkollen Pluton of Norway, and also to other granitic batholiths and is predicted by crystal chemical principles (Nockolds and Allen, 1953; Heier and Adams, 1964; Condie, 1969; etc.).

The plots of K against Rb (Fig. No.16), on Ahron's (1954, Fig. 1) diagram, fall within the area of scatter of granitic and rhyolitic products of highly differentiated magmas showing Rb enrichment (Taylor, et. al 1956). In Dudran area, monzogranite have low values for K/Rb (Av.242) as compared to 620 for the Kongsberg granites of Norway (Kayode, 1974); but are closer to those of the Holterkollen pluton (Av.174. Khalil, et al.1978). According to Kayode (1974), the Kongsberg granites could have formed by normal crystallization from a granitic melt. The lower values in the monzogranite (Av. 242); the quartz-diorite (Av.200) and the granodiorite (Av. 176), points out that all those granites are highly differentiated.

Reynolds (1972), points out that the average crustal value for the K/Rb ratio is 240. Since, the monzogranite has an average value of 242, it may indicate that the source of this granite lay in the crust. Likewise, the similar values for the granodiorite and the quartz-diorite may indicate a crustal source of these granites.

The most significant curve by far is that between Ba and Sr (Fig. No.17). A linear proportional

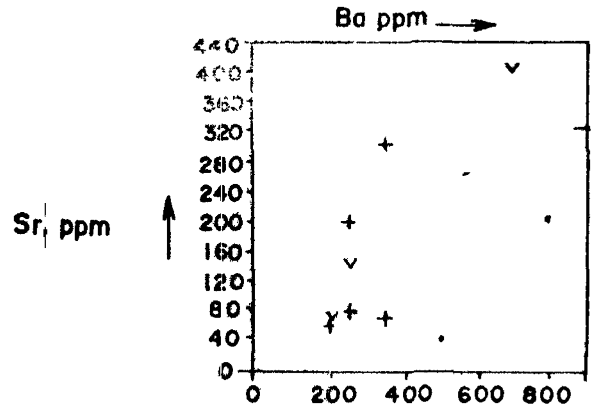

Fig. No. 17 : Sr ppm PLOTTED AS A FUNCTION OF Ba ppm IN THE DUDRAN GRANITES
(Symbols as in Fig.No.1.)

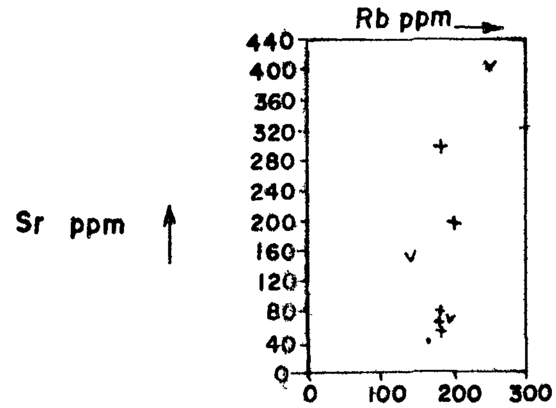

Fig. No. 18 : Sr ppm PLOTTED AS A FUNCTION OF Rb ppm IN THE DUDRAN GRANITES
(Symbols as in Fig. No.1.)

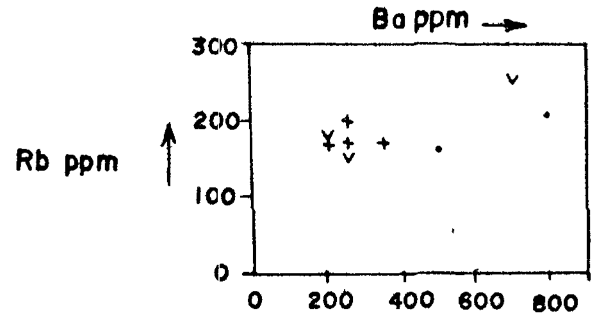

Fig. No. 19 : Rb ppm PLOTTED AS A FUNCTION OF Ba ppm IN THE DUDRAN GRANITES
(Symbols as in Fig.No.1.)

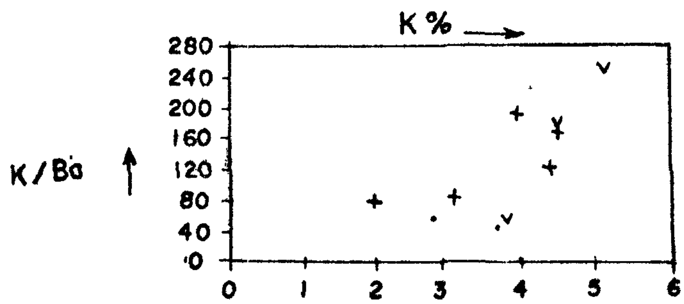

Fig. No. 20 : K/Ba RATIO PLOTTED AS A FUNCTION OF K% IN THE DUDRAN GRANITES
(Symbols as in Fig No.1.)

relation between Barium and Strontium is exhibited in the Dudran granites. The specimens of monzo-granite and the quartz-diorite lying towards the lower end of the curve indicates that they are in a highly differentiated state, relative to granodio-rite. Relationships between Sr and Rb (Fig. No.18) indicate that the monzogranite and the granodiorite are highly differentiated. However, this curve remains horizontal for quartz-diorite.

Heier and Adams (1964), believe that the Ba/Rb ratio may be a discriminating guide to any cry-stal fractionation process. This ratio decreases with fractionation. It is clear from Table-3 that the Ba/Rb ratio for quartz-diorite (Av.1.6) is the lowest for Dudran granites. The low value for this ratio assures their strong differentiation character (Fig. No.19). Similarly, the low value for the monzogranite (av.1.06) and the higher values of 3.5 for the granodiorite, point towards relatively less differentiated nature of the monzogranite and grano-diorite.

Vishwanathan (1972), has discussed the impor-tance of Barium in relation to the crystallization of granitic rocks. He has shown that high K/Ba and low Ba/Rb ratios suggest a highly fractionated magma. The high K/Ba and low Ba/Rb ratios for the monzogranite (Av. K/Ba = 161; Ba/Rb = 1.86) support the contention that these rocks have formed from a highly fractionated magma. Similarly, for the quartz-diorite, the high K/Ba ratio (Av. = 132) and low Ba/Rb ratios (Av. = 1.6) assures highly fractionated nature of quartz-diorite. On the other hand, the low K/Ba ratio (Av. = 50) and High Ba/Rb ratio (Av. = 3.5) for the granodiorite, assures their least fractionated nature. These observations are also supported by the plot of K/Ba versus K% (Fig. No.20). The K/Rb ratio which has been considered as an index of differentiation by many workers has not been found to be a true indicator of differentiation. In some cases K/Rb ratio may lead to a false interpretation. Zlobin and Lebedev (1960) determined K/Rb ratio of two genetically related plutons, Lovozero alkalic rocks and Khibina rocks, and found it be different by as much as 1.5 times. The K/Rb ratio of the granodiorite is the lowest in the area (176), even though it is the least differentiated granite. Erlank (1968), has shown that the general coherence between Potassium and Rubidium is not as close as previously accepted. This means that the K/Rb ratio should be used with caution in crystal fractionation studies.

Chao and Fleischer (1960) had pointed out that the average Zr. content of all granites is 175. It is seen from Table-3, that the monzogranite have an average of 113; the quartz-diorite has an average of 90, whereas the granodiorite has an average of 145. These values are obviously much lower than the average for all granites. In Fig. No.13, Zr. has been plotted against SiO_2 and it is observed that a steady rise in Zr content is paralleled with a rise in SiO_2. This could be due to the enrichment of Zr during fractional crystallization.

Ternary Relations of Rubidium, Barium and Strontium:-

El-Bouseilly and El-Shokkary (1975), plotted the recalculated values of Rb, Ba and Sr (ppm re-calculated to 100%), onto a Ternary Diagram and arrived at differentiation trends for certain groups of Granitic rocks. The plots of Rb, Ba and Sr for the Dudran granites on El-Bouseilly and El-Shokkary's diagram are shown in Fig. No.21. The diagram shows that the quartz-diorite and monzogranite are enriched in Rubidium and are concentrated towards the highly differentiated granite zone with few points lying in the anomalous zone; on the other hand the Rubidium content is seen to be deficient in the granodiorite, which has its concentration towards the zone of normal granites; the latter are also confined towards the Barium apex of the ternary diagram.

As is clear from the diagram, the granodiorites have their maximum concentration in the Zone of Normal Granites. Turekian and Wedepohl (1961), believe these granites to be low-Ca granites. The clustering of these granites is towards the Ba apex, meaning thereby that they are typically associated with high temperature (least differentiated) K-feldspars in normal granites (Taylor, et al., 1960).

Strontium shows a more or less uniform distribution in these granites, whereas increase in Barium is accompanied by a decrease in Rubidium.

The quartz-diorites and the monzogranites have their maximum concentrations in the Zones of Highly Differentiated and Anomalous Granites. As far as the former are concerned, it is the Ba/Rb ratio which characterises the transition from the normal to the highly differentiated granites. Rubidium enrichment has long been known in highly differentiated granites (Ahrens, et al., 1952; Taylor et al., 1956). Such Rb enrichment is explained by the difference in radii between K and Rb (El-Rousseilly and El-Shokkary, 1975).

The anomalous members in these granites show a somewhat unusual distribution of the three index elements. In the ternary diagram the analyses representing this group occupy a field overlapping Granodiorite, Quartz-diorite and Normal granites. In these granites it is noticed that the values of Rb, Ba and Sr are high. This is due to the tendency of these elements to replace K, particularly in the feldspar structure.

The distribution of Rb, Ba and Sr in alkali feldspars has been discussed by Heier and Taylor (1959, a,b). They found that in a differentiation series, Ba decreases more readily than Sr, so that the Ba/Sr ratio decreases with increasing fractionation. From the ternary diagram it is quite clear that in the differentiation sequence granodiorite to quartz-diorite to monzogranite, it is the Sr which decreases while Ba increases. In such a series it is the potassium feldspar : plagioclase ratio which controls the differentiation sequence. Strontium decreases readily with differentiation since it replaces Ca in plagioclase as well as in the K-feldspars, whereas Ba replaces only K in the K-feldspars. The rubidium content in the normal granite or granodiorite remains essentially unchanged.

On the other hand, with respect to the differentiation sequence: normal granite to highly differentiated granites, it is the Ba/Rb ratio which shows the greatest variation, Sr remains virtually constant.

From the ternary diagrams it is clear that low-Ba granites are enriched either in Sr or Rb but not in both. Thus the Ba content seems to govern the Rb/Sr ratio. This ratio tends to show a rise in all the three types.

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Chapter Five

CONCLUSIONS

Field observations, petrological studies and geochemical interpretations have resulted in the recognition of three granite types in the Dudran area of Barmulla district in Jammu and Kashmir. These correspond to the Granodiorite, Quartz-diorite (Tonalite to Trondhjemite to Quartz granodiorite) and Monzogranite, phases of acid magmatism.

Emplacement of the granites has occurred along the foliation planes of the Salkhala metasediments and is syntectonic with the uplift of the Himalayas. The three granites were emplaced at different periods and their relative ages are: Granodiorite (oldest), Quartz-diorite, and Monzo-granite (youngest).

The granites are clearly of magmatic origin. This is borne out by the following:

Field features:-

1) occurrence of the granites in an active orogenic belt and possibly postdating the Panjal eruptives;

2) presence of a chilled margin in the eastern contact and the increase of grain size from periphery towards the core of the granite body;

3) its elongated dome like shape with axis alligned parallel to the regional trend of the country rocks;

4) the presence of contact metamorphic aureoles around the granites;

5) the contacts are sharp and no gradation with the country rocks is seen; also the warping of the country rocks is associated with emplacement tectonics of the granites;

6) the existence of veins and apophyses in the phyllites and the presence of xenoliths in the granites.

<u>Petrographic studies</u> :-

1) the modal values of the three granites reveal their igneous origin;

2) the temperature of crystallization of the three granites has the following ranges :

i) Granodiorite — $860^{\circ}C$ to $880^{\circ}C$.

ii) Quartz-diorite — more than $880^{\circ}C$.

iii) Monzogranite — $800^{\circ}C$ to $880^{\circ}C$.

The above temperatures were evidently obtained in the presence of excess water;

3) the preponderance of 'C' twins over 'A' twins and untwinned plagioclases in all the three kinds of granites;

4) the presence of well-formed zircons in all the three granite types;

5) study of the plagioclase crystal boundaries reveals that the Granodiorite and the Quartz-diorite are hypersolvus, while the monzo-granite is subsolvus.

Geochemical interpretations :-

1) the clustering of the trace elements in the different granites towards the Barium end of the Ternary Diagram, points to a high temperature of crystallization;

2) the granites as revealed by the geochemical trends of the major element oxides, trace element ratios and certain trace elements, crystallized from highly fractionated liquids;

3) geochemical studies reveal that albitization in the three granites has been very weak;

4) trace element interpretations point to the fact that the three granites crystallized from granitic melts.

From the above lines of evidences it can be concluded that the three granites are of igneous origin and that the granodiorite and the quartz-diorite were emplaced in the Epizone, whereas the monzogranite has its source in the deeper Mesozone.

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LIST OF REFERENCES :-

Ahrens, L.H., Pinson, W.H., and Kearns, M.M. (1952): Association of rubidium and potassium and their abundance in common igneous rocks and the meteorites". Geochim. Acta, 2; pp.229-242.

Ahrens, L.H. (1954) : "Quantitative Spectrographic analysis of Silicates". Pergamon, London.

Auden, J.B. (1933): "On the Age of Certain Himalayan Granites". Rec. Geol. Surv. Ind. 66 Pt.4, pp. 461-471.

Bailey, E.H. and Stevens, R.E.(1960) : "Selective Staining of K-Feldspar and Plagioclase on Rock Slabs and Thin-Sections". Amer. Mineralogist. 45: pp.1020-1025.

Balk, R. (1937) : "Structural Behaviour of Igneous Rocks". Mem. Geol. Soc. Amer. 5: 177 p.

Barth, T.F.W. (1969) : "Feldspars". John Wiley and Sons, New York. 261 p.

Bion, H.S. (1928) : "The Fauna of the Agglomeratic Slate Series". Rec. Geol. Surv. Ind. 41/2: 115 p.

Buerger, M.J. (1945) : "The genesis of twin crystals". Amer. Mineralogist. 30 : 469 p.

Buddington, A.F. (1959) : "Granite Emplacement with special reference to North America". Bull. Geol. Soc. Amer. 70: 671-748 pp.

Chao, E.C.T., and Fleischer, M. (1960): "Abundance of Zirconium in Igneous Rocks". Proc. Insl.Geol. Congr. 21st Sess. Pt.1 : 106-131 pp.

Chayes, F. (1956): "Petrographic Modal Analysis". Wiley, New York. 113 p.

Condie, K.C. (1969) : "Petrology and geochemistry of the Laramie batholith and related metamorphic rocks of Precambrian age, eastern Wyoming". Bull. Geol. Soc. Amer. 80 : pp. 57-82.

Condie, K.C. and Lo, H.H. (1971): "Trace element geochemistry of the Louis Lake Batholith of early Precambrian age, Wyoming". Geochim.Cosmochim. Acta, 35: pp.1099-1119.

Crowder, D.F., and Ross, D.C.(1973): "Petrography of some Granitic Bodies in the Northern White Mountains, California-Nevada". U.S.G.S. Proff. Paper-775, 28 p.

Davis, G.A. (1963) : "Structure and mode of emplacement of Caribou Mountain pluton, Klamath Mountains, California". Bull. Geol.Soc. Amer. 74: pp. 331-348.

Desio, A., Tongiorgi, E., and Ferrara, G. (1964): "Geological age of some granites of the Karakoram, etc. Central Asia". Rep. 22nd. Int.Geol. Congr. Pt.11. pp.479-493.

Donnay, J.D.H. (1940): "Width of albite-twinning lamellae". Amer. Mineralogist, 25: 578 p.

Donnay, J.D.H. (1943) : "Plagioclase twinning". Bull. Geol. Soc. Amer. 54, 1645 p.

El-Bouseilly, A.M. and El-Sokkary, A.A. (1975): "The relation of Rb, Ba and Sr in granitic rocks". Chem. Geol. 16 : pp. 207-219.

Emmons, R.C. and Gates, R.M. (1943) : "Plagioclase Twinning". Bull. Geol. Soc. Amer. 54. pp. 287-304.

Emmons, R.C. and Mann, V., (1953) : " A twin-zone relationship in plagioclase feldspar". Mem. Geol. Soc. Amer.52. pp.41-54.

Erlank, A.J., (1968) : "Terrestrial abundance relationship between potassium and rubidium". In L. Ahrens (Editor), 1st Meet. Int. Assoc. Geochem. Cosmochem., Int. Ser. Monogr. Earth Sci., vol. 30. Pergamon, London.

Flehmig, W. (1977) : "The synthesis of Feldspar at temperatures between 0^{o}-80^{o}C, their ordering behaviour and twinning". Contrib. Mineral. Petrol.65. pp.1-9.

Gansser, A. (1964,a): "The Alps and the Himalayas". Rep.22nd Int. Geol. Cong. 11. pp.387-399.

-do- (1964,b): "Geology of the Himalayas". Interscience Publishers, New York.

Gay, P., (1956): "A note on albite twinning in plagioclase feldspar". Mineral. Mag. Vol.31, pp. 301.

Ghose, N.C., and Singh N.K. (1977) : "Experimental study of granitic rocks of Darjeeling (West Bengal) India, and its application to the origin of the Himalayan Granites". Tectonophysics. 43: pp.23-41.

Goldschmidt, V.M. (1937) : "The principles of distribution of chemical elements in minerals and rocks". Jour. Chem. Soc. London.2: pp.655-673.

Gorai, M. (1951) : "Petrological studies on Plagioclase Twins". Amer. Mineralogist. 36: pp.884-901.

Harker, A (1909): "The natural History of Igneous Rocks". New York, pp.

Heier, K.S., and Adams, J.A.S.(1964): "The geochemistry of the alkali metals". Phys. Chem. Earth.5: pp.253-281.

Heier, K.S., and Billings, G.K.(1970): "Rubidium". In Wedepohl, K.H., Correns, C.W., Shaw, D.M., Turekian, K.K., and Zeman,J. (Editors) "Handbook of Geochemistry". 11-2. Springer-Verlag, Berlin.

Heier, K.S., and Taylor, S.R.(1959, a) : "Distribution of Li, Na, K, Cs, Pb and Tl in Southern Norwegian Precambrian alkali feldspars". Geochim. Cosmochim. Acta., 15: pp.284-304.

-do- (1959,b): "Distribution of Ca, Sr and Ba in southern Norwegian alkali feldspars". Geochim. Cosmochim. Acta. 17: pp.286-304.

Heinrich, E.W. (1956): "Microscopic Petrography". McGraw Hill, Inc., New York, 286 p.

Kaul, M.K. (1976) : "On the local stratigraphy, structure and mineralisation in the Hapathkhai Valley, Buniyar area-Kashmir" - Sem. Him. Geol. Sec.IV, New Delhi.

Kayode, A.A.(1974): "Petrography and geochemistry of granites in the Kongsberg area, South Norway"- Norsk. Geol. Tidsskr., Vol.54, pp.269-293.

Khalil, S.O., Neff, T.A. and Brunfelt, A.O. (1976): "Trace element abundances of the Holterkollen pluton complex, Oslo area, Norway". Chem. Geol. Vol.22,pp.121-155.

Kohler, A. (1949, a): "Recent results in the investigation of feldspars". - Jour. Geol. Vol. 57. 592 p.

Krishnan, M.S. (1968) : "Geology of India and Burma". Higginbothams (P) Limited, Madras; 536 p.

McCarthy, T.S., and Hasty, R.A. (1976) : "Trace element distribution patterns and their relationship to the crystallization of granitic metals". - Geochim. Cosmochim. Acta. Vol.40. No.11. pp.1351-1358.

Middlemiss, C.S. (1912) : "Sections in the Pir Panjal Range and Sind Valley, Kashmir".- Rec. Geol.Surv. Ind. Vol.41. pt.2.

Nockolds, S.R., and Allen, R.(1953) : "The geochemistry of some igneous rock series".- Geochim. Cosmochim. Acta. Vol. 4. pp.105-142.

Parsons, I. (1978) : " Feldspars and fluids in cooling plutons". - Mineral. Mag. Vol.42. No.321. pp.1-17.

Parthasarthy, T.N. (1969) : "On the gneisses of the Sainj and Tirthan valleys, Kulu Himalayas and their origin". Bull. Geol. Soc. India. Vol.6. p.23.

Pascoe, E.H. (1950) : "Manual of Geology of India and Burma". - Vol.1. Govt. of India Press, Calcutta, pp.1-483.

Pascoe, E.H. (1960) : "Manual of Geology of India and Burma".- Vol.2. Govt. of India Press, Calcutta, pp.485-1343.

Prasad, E.A.V. (1966): "On the elimination of plagioclase twinning". - Ind. Acad.Sci. 64B, p.295.

Raina, K.B.(1977): "A note on the Galena and Sphalerite occurrences of Buniyar area, Baramulla district, Jammu and Kashmir". Geol.Surv. Ind. Misc. Pub. No.27. pp.181-187.

Ray, S. (1972): "Petrogeny of the Himalayas - a brief study of its granites". Him. Geol. Vol.2. pp.564-573.

Reynolds, R.C. (1972): "Rubidium: Element and Geochemistry". Encyclopedia of Geochemistry and Environmental Sciences; Editor: R.W.Fairbridge.- Van Nostrand Reinhold Co. London. pp.1050-1051.

Seifert, K.E. (1964): "The genesis of plagioclase twinning in the Nonewaug granite".- Amer. Mineral. Vol.49. No.3 & 4. pp.297-320.

Sharma, V.P. (1974): "Sulphide mineralisation in North-West Himalaya and its relationship with the magmatic activity". Abst. Intl. Sem. on Tect. and Metall. of South-East Asia and the Far-East.

-do- (1977): "An account of the Bandal batholith Kulu district, H.P.". Rec. Geol. Surv. Ind. Vol.108. Pt.2. pp.104-111.

Smith, J.V. (1962): "Genetic aspects of twinning in feldspars".- Norsk. Geol. Tidsskr. Vol.42. pp.244-263.

Streckeisen, A.L. (1967): "Classification and Nomenclature of Igneous Rocks".- N.Jb.Miner. Abh. Vol.107. No.2 & 3. pp.144-240.

Taylor, S.R., Emeleus,C.H. and Exley, C.S.(1956): "Some anomalous K/Rb ratios in igneous rocks" and their petrological significance".- Geochim. Cosmochim.Acta. Vol.10. pp.224-229.

-do- and Heier, K.S.(1960): "The petrological significance of Trace Element variations in alkali feldspars".- 21st. ~~Sesst~~ Intl. Geol. Congr. Copenhagen, Rept. Pt.14. pp.47-61.

-do- (1965): "The application of trace element data to problems in petrology".- Phys. and Chem. of the Earth, Vol.6, Editor : L.H. Ahrens, pp. 133-214.

Tobi, A.C. (1962) : "Characteristic patterns of plagioclase twinning." - Norsk. Geol. Tidsskr. Vol. 42, pp. 264-271.

Turekian, K.K. and Wedepohl, W.H. (1961). "Distribution of the elements in some major units of the earth's crust". - Geol. Soc. Amer. Bull. Vol.72. pp.175-192.

Turner, F.J. (1951): "Observations on twinning of plagioclase in metamorphic rocks".- Amer. Mineral. Vol.36. No.7 & 8.pp.581-589.

Turner, F.J. (1968): "Metamorphic Petrology - Mineralogical and field aspects".- McGraw Hill Book Company, New York, 403 p.

Tuttle, O.F. (1952): "Origin of contrasting mineralogy of extrusive and plutonic salic rocks".- Jour. Geol. Vol. 60. pp.107-124.

-do- and Bowen, N.L. (1958): "Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KalSi_3O_8$ SiO_2-H_2O."- Geol. Soc. Amer. Mem. Vol.74.

Vance, J.A. (1961): "Polysynthetic twinning in plagioclase".- Amer. Mineral. Vol. 46, No.9 & 10. pp. 1097-1119.

-do- (1962): "Observations on the rhombic section of a zoned plagioclase crystal".- Mineral. Mag. Vol.33, pp.125-131.

Valdiya, K.S.(1962): "A study of the Champawat Granodiorites and associated metamorphites of the Lohagat sub-division, district Almora-U.P., with special reference to petrography and petrogenesis".- Ind. Mineral. Vol.3, pp.6-37.

Wadia, D.N. (1928): "The Geology of Poonch State (Kashmir) and adjacent portions of the Punjab".- Mem. Geol. Surv. Ind. Vol.51, Pt.2, pp.185-370.

Wadia, D.N. (1932) : "The Syntaxis of North-West Himalayas : Its rocks, tectonics and orogeny".- Rec. Geol. Surv. Ind. Vol.65, Pt.2, pp.189-314.

-do- (1934) : "The Cambrian-Trias sequence of North-Western Kashmir (parts of Muzaffarabad and Baramulla District)".- Rec. Geol. Surv. Ind. Vol.68, Pt.2, pp.122-176.

White, A.J.R. (1966): "Genesis of migmatites from Palmer region of southern Australia".- Chem.Geol. Vol.1, pp.156-200.

Vishwanathan, S. (1972): "Geochemistry of barium in granitic rocks from an early Precambrian greenstone-granite belt."- Ind. Mineral Vol.13, pp.1-13.

Zlobin, B.I. and Lebedev, V.I. (1960): "Geochemical relationships of Li, Na, K, Rb and Tl in alkalic magmas and its Petrogenetic significance".- Geokhimiya. Vol.2, pp.101-124.

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TABLE - I -

MODAL ABUNDANCES ON THE DUDRAN GRANITES :

Rock type.	Sample No.	% Quartz	% Plagio-clase	% K-Feld-spar	% Bio-tite	% Musco-vite	% Epi-dote	% Acce-ssory	Total
Quartz-diorite	DG_A-3/8	42.37	24.03	0.72	22.64	5.32	4.34	0.58	100
	DG_C-1/11	33.18	56.19	0.59	6.52	1.89	1.37	0.26	100
	DG_E-1/14	39.35	27.95	—	18.33	—	14.37	—	100
	DG_H-1/18	34.83	35.03	0.49	20.00	5.85	1.46	2.34	100
	DG_I-1/20	44.59	50.09	—	3.94	0.59	—	0.79	100
Monzo-granite	DG_D-1/9	35.30	29.60	22.85	8.94	2.18	1.06	0.07	100
	DG_D-1/13	21.44	33.58	37.44	5.28	0.92	1.17	0.17	100
	DG_D-4/13	33.47	24.10	27.10	11.15	2.99	1.19	—	100
Grano-diorite	DG_F-1/17	39.44	41.38	7.07	9.59	0.78	1.26	0.48	100
	DG_G-1/18	29.00	32.90	6.40	18.70	0.70	2.90	1.40	100

TABLE - I

MODAL ABUNDANCES ON THE DUDRAN GRANITES :

Rock type.	Sample No.	% Quartz	% Plagio-clase	% K-Feld-spar	% Bio-tite	% Musco-vite	% Epi-dote	% Acce-ssory	Total
Quartz-diorite	DG_A-3/8	42.37	24.03	0.72	22.64	5.32	4.34	0.58	100
	DG_C-1/11	33.18	56.19	0.59	6.52	1.89	1.37	0.26	100
	DG_E-1/14	39.35	27.95	—	18.33	—	14.37	—	100
	DG_H-1/18	34.83	35.03	0.49	20.00	5.85	1.46	2.34	100
	DG_I-1/20	44.59	50.09	—	3.94	0.59	—	0.79	100
Monzo-granite	DG_D-1/9	35.30	29.60	22.85	8.94	2.18	1.06	0.07	100
	DG_D-1/13	21.44	33.58	37.44	5.28	0.92	1.17	0.17	100
	DG_D-4/13	33.47	24.10	27.10	11.15	2.99	1.19	—	100
Grano-diorite	DG_F-1/17	39.44	41.38	7.07	9.59	0.78	1.26	0.48	100
	DG_G-1/18	29.00	32.90	6.40	18.70	8.70	2.90	1.40	100

TABLE — 3

CHEMICAL ANALYSIS OF GRANITIC ROCKS IN DUDRAN AREA

Rock type	Granodiorite			Quartz diorite				Monzogranite		
Sample No.	F	G	A	C	E	H	I	B	D	D
	Chemical Analysis (Weight percent)									
SiO_2	62.94	54.32	58.34	60.65	52.83	56.18	66.15	63.12	59.58	62.08
Al_2O_3	13.17	14.76	11.06	15.83	9.72	13.98	13.52	13.24	15.69	13.19
Fe_2O_3	2.10	3.97	4.81	1.42	3.84	4.23	0.86	1.97	1.18	2.46
FeO	2.57	4.87	5.90	1.75	4.72	5.20	1.06	2.42	1.44	3.02
MgO	2.39	4.51	5.46	1.62	4.36	4.81	0.98	2.24	1.33	2.79
CaO	7.42	5.72	4.18	11.08	4.80	6.10	0.03	5.36	6.13	4.35
*Na_2O	1.56	1.26	0.17	2.55	2.05	1.70	1.50	2.30	2.71	1.73
*K_2O	3.93	2.96	4.15	2.16	4.85	4.67	3.31	4.80	5.47	4.09
H_2O	1.67	6.22	5.32	1.74	2.45	5.17	0.81	2.23	1.15	2.88
Total	97.75	98.59	99.34	100.80	89.62	102.04	88.22	97.68	94.68	96.59

(ii)

TABLE — 3 (Contd.)

	F	G	A	C	E	H	I	B	D	D
	Niggli Numbers									
al	28.7	27.5	21.5	24.1	19.2	24.1	50.8	33.5	35.6	30.8
fm	26.9	43.6	54.5	18.1	45.8	43.1	18.7	29.4	15.5	33.7
c	29.4	19.3	14.8	43.7	17.6	19.2	0.0	24.7	25.2	18.6
alk	16.9	9.7	9.3	14.1	17.4	13.6	30.2	12.4	23.6	16.9
si	233.00	171.00	191.00	223.00	180.00	165.00	420.00	271.00	230.00	247.00
k	0.6	0.6	0.9	0.4	0.6	0.6	0.6	0.2	0.6	0.6
mg	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	00.5
	Semiquantitative spectrographic analysis (ppm)									
Pb	10	10	10	35	25	25	10	30	25	10
Cu	25	70	30	15	25	15	25	25	25	30
Ni	30	40	25	45	30	30	30	30	30	40
Co	10	10	L-10	10	L-10	L-10	10	L-10	L-10	10
Sn	L-10	L-10	L-10	L-10	L-10	20	L-10	L-10	L-10	L-10

TABLE - 3 (Contd.)

	F	G	A	C	E	H	I	B	D	D
	Semiquantitative spectrographic analysis (ppm) (Contd.)									
Ga	15	10	10	20	10	15	15	15	15	20
Zr	180	110	60	120	80	90	100	120	120	100
V	180	100	60	170	60	60	140	50	50	70
Cr	280	80	70	250	200	250	280	300	100	225
Ba	800	500	200	250	250	350	350	250	200	700
Sr	200	40	60	80	200	300	70	140	70	400
Nb	L-20	20	20	L-20	L-20	L-20	20	L-20	L-20	20
Ge	L-5	L-5	L-5	L-5	L-5	L-5	L-5	L-5	L-5	L-5
Ag	L-1	L-1	L-1	L-1	L-1	L-1	L-1	L-1	L-1	L-1
Mo	L-5	L-5	L-5	L-5	L-5	L-5	L-5	L-5	L-5	L-5
La	60	L-30	L-30	L-30	L-30	90	L-30	L-30	L-30	80
Y	20	L-20	L-20	L-20	30	20	L-20	30	L-20	L-20
Rb	200	160	170	170	200	170	170	150	180	250
Li	25	40	4	50	15	20	25	5	5	30

(iv)

<u>TABLE - 3 (Contd.)</u>

	F	G	A	C	E	H	I	B	D	D
	Some elemental ratios and element percentages									
K/Rb	181.31	170.63	225.30	117.15	223.63	252.33	179.63	294.85	280.29	150.69
Rb/Sr	1.00	4.00	2.83	2.13	1.00	0.57	2.43	1.07	2.57	0.63
Ba/Rb	4.00	3.13	1.18	1.47	1.25	3.06	2.06	1.67	1.11	2.80
K/Ba	45	55	191	80	179	123	87	177	252	54
K%	3.63	2.73	3.83	1.99	4.47	4.31	3.05	4.42	5.05	3.71
Na%	1.28	1.04	0.14	2.10	1.69	1.40	1.34	1.90	2.23	1.42

N.B. L = Stands for less than.

* = These values were analyzed, rest were recalculated from modal abundances.